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OBSERVATIONS OF *JUPITER* WITH A FIVE-INCH REFRACTOR, DURING THE YEARS 1879–1886.

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During the years 1879 and 1880 I was constantly employed in the daytime with my business duties; but every possible opportunity was used in astronomical observations at night. The latter part of 1879 and the major part of 1880 were devoted to an extended series of observations and drawings of *Jupiter*.

These observations were made at Nashville, Tennessee, ($\lambda = +0^h39^m.0$; $\phi = +36° 10'$), and before I was connected with the Vanderbilt University Observatory.

The telescope was a five-inch refractor, mounted on a portable tripod, without a driving clock. A magnifying power of 173 diameters was nearly always employed—the instability of the mounting preventing the use of a much higher power. A right-angled prism was used with the eye-piece. This shows the planet reversed, but not inverted. In sketching, a small wooden box or desk was used, with a glass in the top, on which the paper was laid. A faint illumination from below, through the sketching paper, was obtained from the reflected light of a candle. By this means I could sit with the desk on my knees and compare the telescopic image directly with the drawing.

The drawings were very carefully made, and faithfully show the markings as they appeared upon the planet at the time of observation. Professor HOLDEN has lately seen these drawings, and suggested that I collect them together and prepare them for reproduction by photo-lithography. I have, therefore, selected forty-five of them as fairly representing the phenomena of *Jupiter* during the period of observation, and they are reproduced in Plates I, II, III, IV, following. Constant reference should be made to the plates by the reader. In these plates the top of each drawing is north; the bottom is south;

the right-hand side is east, or following; the left-hand side is west, or preceding.

During the observations the usual appearance of the planet was about as follows: Around the equatorial regions was a broad band or belt, which could really be said to be two belts; for it was always divided longitudinally by a sinuous, lighter portion, which was sometimes much broken by diffusions from the belts and by cloud-like forms. In the observations, I have considered this great belt as two, and have called the parts, respectively, the north and the south equatorial belts, or, collectively, the equatorial belt. Considered as one, the belt was about one-fifth the polar diameter of the planet in width.

Just south of the equatorial belt was situated the Great Red Spot, covering an area of over two hundred million square miles—greater than the entire surface of our earth.

On the inner part of the south equatorial belt was frequently seen a brilliant white spot, which had a very strong proper motion with reference to the Red Spot.

To the north of the equator were situated three narrow lines or belts. I have designated these as the first, second and third linear belts. The third was usually the border of the north polar cap, while the first became the scene of remarkable changes about the 1st of November, 1880.

What principally attracted my attention to the planet was the appearance of the Great Red Spot. The early history of this object seems to be rather obscure, but it was certainly seen as early as July, 1878, by Professor PRITCHETT, at Glasgow, Missouri, and was probably seen at intervals as early as 1870.

It was first seen by me in the early morning of August 3, 1879. I had heard nothing of it; and while observing and sketching *Jupiter* it came into view around the following limb, and was so remarkable in form and color that I was at once struck with its appearance. On this date the form of the spot was different from what it was at any of my subsequent observations. While the south edge of the spot was nearly straight and the following end blunt, the north edge tapered towards the preceding end, strikingly like the drawing by TROUVELOT in the *Observatory* for April, 1879 (p. 411).

It will be seen that my drawings nearly all show some phase of the Red Spot. I have so selected them because it was the principal object of interest with a small telescope, and therefore received the most attention. Though the Red Spot was watched carefully, I never saw any details on its surface until the latter part of the obser-

vations, when a whitish cloud formed upon it. Changes were sometimes seen, however, in the form of the spot. These were confined to the ends, which occasionally appeared rounded, and, again, were very much pointed, or cigar-shaped. Faint trails were frequently seen running from one end or the other of the spot, and sometimes from both ends at the same time; the most persistent of these was the trail from the preceding end.

One of the most interesting features of the Great Spot was the repulsion it seemed to exert upon adjacent markings on the planet. For a time it was surrounded by a sea of light that completely encircled it for a distance of three or four thousand miles (see drawing of October 3, 1879), and which appeared as a visible barrier against the approach of any spot or marking. So manifest was this repellant force that, as early in the observations as 1879, I called attention to it in the *English Mechanic* (Vol. 30, p. 166).

There was, however, one striking exception to this general rule: In July, 1880, a dense, smoky shading was seen apparently attached to the south side of the Red Spot, extending to the south preceding, and covering an area but little less than the Great Spot itself. This eventually passed the Red Spot, and, having a shorter period, soon left it far behind, and finally became squeezed out into a short longitudinal belt or spot, some twenty-five or thirty thousand miles long. Two white belts, one on each side, seemed to compress it into a definite form, that now extended east and west, instead of southwest and northeast, its primitive direction.

During the observations, a great number of estimates were made of the instant that the Great Spot was in transit across the central meridian of the disc of *Jupiter*. In discussing his micrometer measures of such transits from June to December, 1880, on thirty-one days, Prof. HOUGH says that his observations "gave for the mean error of a single pair of measures $\pm$ $0^m.9$, and for the average mean probable error for any day, $\pm$ $0^m.4$, on the observed transit of the Red Spot over the central meridian," and further remarks: "It may be inferred from these results that the use of a micrometer is infinitely preferable to any method of estimation." Among the observations of the Red Spot I have forty-four complete and carefully estimated transits—that is, observations of the preceding end, middle, and following end of the spot. Twenty-one of these are from a single but careful estimate of each phase. These give the probable error of a transit of the center from the mean of the three observations = $\pm$ $1^m.0$. In twenty-three of these transits three estimations were

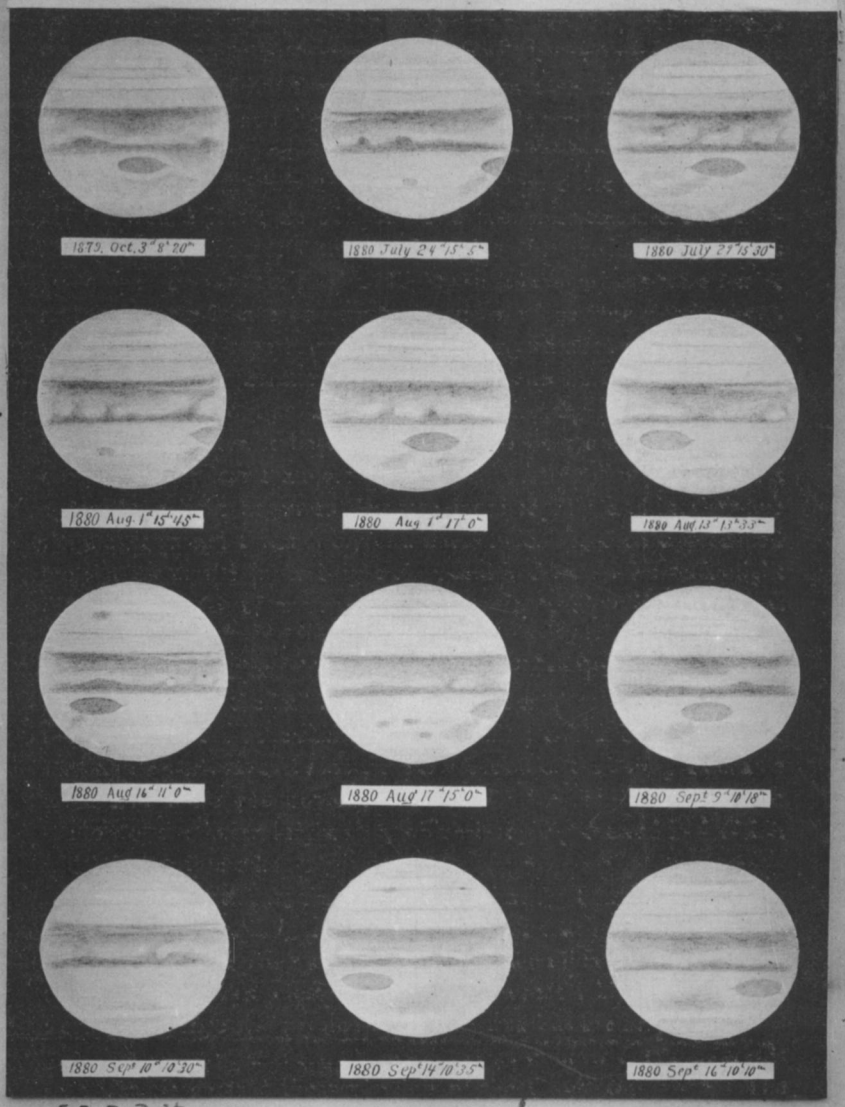
made of each phase; from these I get for the transit of the middle from the mean of the nine observations the error of the transit, $= \pm 0^m.7$. These values are comparable with the best micrometer measures. It is evident that they should be so. The Red Spot moves through an angle of about $0°.6$ in 1^m. At transit this amounts to a change of distance from the limb of about $0''.2$. It is clear, that with a five-inch telescope the position of the spot could not have been fixed more closely with a micrometer (even if I had been provided with one, which was not the case) than it was by the method of transits. I think the sole advantage of micrometer measures in a case of this kind is that they can be made *near* the transit, thus saving time by not having to wait for special phases, and that they can be repeated until the accidental error of the result is reduced to a small quantity.

I have inserted the above comparisons to show what accuracy may be obtained by carefully made estimates, and as an encouragement to those who have not all the accurate appliances of an observatory to work with.

During the observations, which frequently extended over an interval before the appearance of the Red Spot at the following limb and until after it had disappeared at the preceding limb, I several times noted the moment when the first trace of the Red Spot could be seen at the *f.* limb. The mean of seven such observations, compared with the observed transit of the center of the spot, gave the interval $2^h\ 1^m$ from the first trace of the *p.* end of the Red Spot at the *f.* limb, until the center of the spot was in transit. This gives 1^h36^m as the time that a mark of the same distinctness as the Red Spot, and at the same distance from the equator, could be seen before its transit; $3^h\ 12^m$ is, therefore, the total duration of visibility of *any* point of the Red Spot during a rotation. Thus the spot could never be altogether invisible through rotation for a greater interval than 5^h53^m from the time the *f.* end disappeared at the *p.* limb until the *p.* end reappeared at the *f.* limb. The mean of two estimates gave 1^h9^m as the interval between the time when the spot was clearly seen free within the *f.* limb and the time of transit of its center. Slight variations in the tint and depth of color of the spot were noticed, and it was frequently contrasted with some portion of the equatorial belt; but as the belt itself was probably subject to a far greater change in depth and color than the Red Spot, such a comparison would not be very conclusive proof of change.

It would take up too much space to give the observations, even in

Plate I



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an abbreviated form, so I shall briefly summarize the most important points:

THE COLOR OF THE RED SPOT.

1879. Aug. 2, it is described as of the color of red-hot iron.

1880. July 11, a clear, darkish Indian red, brighter in color than equatorial belt; July 24, a clearer red than equatorial belt; July 29, a light Indian red, the belts a duller red; Aug. 16, a brick-dust color—same tint as north equatorial belt; Sept. 14, a lighter red, very much lighter than north belt; Sept. 16, a brick red, more strongly marked than the north band; Sept. 25, a deep brick-dust color; Sept. 30, a distinct red, the equatorial bands a heavier red; Oct. 7, a redder color than the belts; Oct. 13, a heavy red, clear and sharp; Oct. 20, a light, clear red; Nov. 1, a pale red; Nov. 3, a deep brick-dust color; Nov. 11, a solid red, well outlined; Nov. 20, a little less deep in color, but very much redder than the belts.

1881. Jan. 7, not so well defined at edges, but a deeper tint at the middle; July 2, a pale light red; July 9, the spot is even of a deeper tint than last year; Oct. 31, lightish red.

1882. Jan. 23, faintish red, very pale.

1885. April 25, it is very faint—quite difficult to observe—a very pale red; April 28, it is very well seen, and is clearly outlined all round; May 12, very faint; May 15, fairly distinct, probably a white mass superposed on it.

1886. April 8, a long white cloud clearly seen on the Red Spot; April 22, very faint, a whitish strip of cloud on it, north of middle.

TRAILS FROM THE ENDS OF THE RED SPOT.

Faint reddish trails were recorded on the following dates:

1879. Oct. 3, faint trail from following end.

1880. July 11, faint trail from preceding end; July 18, faint trail from each end; Aug. 16, faint trail from each end; Aug. 30, faint trail from each end; Sept. 16, faint trail from each end; Nov. 18, faint trail from preceding end; Nov. 20, faint trail from preceding end.

1886. Nov. 5, faint trail from preceding end.

These usually were about 2″ or 3″ long.

SIZE OF THE RED SPOT.

Frequent estimations were made, at the telescope, of the relative size of the Red Spot, on dates extending from July, 1880, to December 14, 1880. Following are the estimations:

Breadth: From twelve estimates of its breadth north and south, it was just perceptibly less than one-half the breadth of the equatorial band = estimate I; while eight estimates made it exactly one-half = estimate II. One estimate placed it perceptibly greater than one-half = estimate III.

Length: Sixteen estimates made the length very slightly less than one-third the length of the same parallel of the disc of *Jupiter* = estimate I; while the mean of six other estimates made it 0.32 that distance in length = estimate II.

Distance of North Edge of Spot from South Edge of Belt: Twenty-four estimates of the distance between the north edge of the spot and the south edge of the equatorial belt gave it 0.40 of the width of the spot, with decided and considerable variability (which never, however, exceeded one-half).

Adopting from the *Report* of the Dearborn Observatory for 1882 Professor HOUGH'S micrometer measures of the breadth of the equatorial bands (for a period exactly covering my estimation) as = 7″.04, and his value for the radius of the parallel of the center of the Red Spot = 17″.94, we have the above estimations expressed in seconds of arc at the distance unity.

BREADTH OF SPOT: Estimate I = very slightly less than 3″.5.
Estimate II = 3″.5.
Estimate III greater than 3″.5.

LENGTH OF SPOT: Estimate I = very slightly less than 12″.0.
Estimate II = 11″.5.

DISTANCE NORTH EDGE OF SPOT FROM SOUTH EDGE OF BELT: Assuming, with the above estimates, the breadth of spot to equal 3″.5, the estimates give the distance above as 1″.4.

THE BAY AT THE RED SPOT FORMED BY THE SOUTH EQUATORIAL BELT.

This singular recurring feature of the south equatorial belt is worthy of particular attention. As it seems intimately connected with the Red Spot, it had best be mentioned here. In a drawing published in the *Observatory* for April, 1879 (p. 411), TROUVELOT shows a sharp curvature of the south side of the equatorial belt around the preceding end of the Great Spot, forming, as it were, a bay. He says it had disappeared and reappeared no less than three times in a little over a year, always reappearing at the same place with reference to the Red Spot. This bay, or a similar one, is shown in my drawing of October 3, 1879. It then curved south, following

the Red Spot, the southern limit diffusing very greatly, but sharply terminated where it curved down following the spot. It is shown thus also in a drawing of September 14, 1879. It was wholly absent throughout 1880, the south edge of the equatorial band being perfectly straight all around the planet. The first indication I have of its return is February 4, 1882, (the observations had, however, ceased to be continuous after 1880), when I recorded that the south equatorial band "appeared to blend southwards, following the Red Spot." In 1885, this feature was distinctly marked—the appearance being the same as in 1879, except that its extreme south edge did not blend so much as in that year. Its presence was marked on April 25, May 12, May 15, and, 1866, April 22, when the planet was examined. The absence of other dates indicates only that the region of the Red Spot was not examined, and not that the bay existed only on these dates. At the Lick Observatory I have seen it frequently at the present opposition just as it was in 1879. That this is intimately connected with the forces that produce the Red Spot there is no doubt. In connection with this feature and the Red Spot, I would mention a singular thin red line that sprung out from the south edge of the equatorial band like a spur, and, curving backwards, ran along parallel to the south edge of the equatorial belt for some distance. This is shown in the drawings of 1880, September 18, 28, 30, and October 10. Prof. HOUGH has figured this singular object in a drawing made September 9, 1880, with the 18½-inch refractor, just as I have seen it, except that he does not show it of a red color. (See *Report Dearborn Observatory*, 1882.) It occupied a place near the preceding curve of the bay. Though this spur-line joined the south edge of the equatorial belt, to which it seemed attached, it did not partake of its motion; for throughout its visibility it retained the same position with reference to the Red Spot, showing that its period was the same as that of the spot, while the period of the belt is about $5\frac{1}{2}^{m}$ shorter.

I have already mentioned the smoky shading which, in July, 1880, seemed to be attached to the Red Spot, and which finally passed by it through a more rapid rotation. It is shown on a great many of the drawings. I would specially call attention to those of Pl. I (July 24, 29, August, 16, 17, September 9, 11); Pl. II (September 30, October 7, 10, November 1). The drawing of July 24, 1880, shows a very small spot near transit in the southern hemisphere. This small spot was usually quite hard to see, but was clearly defined and dusky when best seen; it was probably about 4000

miles long and some 2000 miles wide. The remarkable features were its permanency and its slow rotation period. Its period being somewhat less than the Red Spot, it slowly drifted westward from that object, and probably, in course of time, completed a circuit of the planet, which it would do in a little over two years, when it would again be in the region of the Red Spot. It is shown in several of the drawings.

THE EQUATORIAL WHITE SPOT.

Throughout the entire period of my observations, there was present on the planet a very remarkable White Spot, situated on, or generally imbedded in, the north edge of the south equatorial band. This object was subject to remarkable changes of form and brightness. It required but a few observations to show that it was in rapid motion with reference to the Red Spot. Its period was nearly five and a-half minutes shorter than that of the Great Spot. Its westward drift with reference to that object was about 8° of longitude per day, or about 2430 miles, at every rotation of the planet. This rapid relative motion with reference to the Red Spot would therefore carry it completely around the planet in forty-five days, and a number of such revolutions were actually observed. It required but four days for this swiftly moving body to completely pass the Red Spot, which it soon left far behind, and in twenty-two and one-half days it would be on the opposite side of the planet. I would refer to the drawings of Plate III (November 18, 20, 22 and 23), where one of these passages of the Red Spot is shown. The motion of this object was not perfectly uniform. At times it seemed to slacken its speed, and then to spurt forward again. Among the surprising things about this spot were its great changes, both of form and brightness. At times it became so bright as to glisten like a star. When in this condition it was by far the brightest object on the planet. For a while it would appear as a rather small, inconspicuous, light, oval spot, imbedded in the dark matter of the north edge of the south equatorial band. In this state it would scarcely attract attention. It would next be seen brilliantly white, burying its head in the dusky matter of the belt, with a vast, luminous train streaming backwards along the equatorial regions, like the tail of a comet. Sometimes this train was composed of white, cloud-like balls, that streamed eastward on the planet. After continuing thus for some time, it would seem to have wasted its energies, and would then assume the quiescent state. I have tried to connect these changes of brightness with the changes of motion, but have not been able to do so, though there

is doubtless a relation between them. When at its brightest it seemed to burrow in the south band and plow the matter before it. A long, sinuous rift in the northern part of the north equatorial band had constantly the same relative position to the White Spot, and was perhaps in the same layer of the planet's atmosphere. Probably all the objects in the equatorial regions had the same motion as the White Spot, or were stationary, relative to it. Indeed, the entire belt is revolving around the planet once in forty-five days, relatively to the Red Spot.

I will select a few of the many notes I have on this object and those connected with it:

1880. Aug. 13 (13^h 33^m), a brilliant white spot appearing at the *f.* limb; Aug. 16 (11^h), very white; Aug. 18, bright spot n. f. Red Spot, followed by light, cloudy masses; Aug. 23, the bright spot of the 18th has toned down; Aug. 30, bright; Sept. 10 (10^h 30^m), brilliant, with train; Sept. 15 (9^h 30^m), very bright, with train of white, cloudy masses; Sept. 24 (about 9^h), a bright head, with long, curved stream of white matter following; Sept. 28 (11^h 30^m), bright; Sept. 31 (7^h 33^m), two large white spots about midway the disc, a smaller one between them—they all shine with a very white luster; Nov. 11, a great number of white balls seen near 10^h; Nov. 18, white; Nov. 20, it is more isolated from the other matter—pale white, diffused at edges; Nov. 22, smaller and pale, about the size of Satellite I, but much paler; Nov. 23, it is smaller and paler; Nov. 24 (9^h 20^m), light; Nov. 29, white. When best seen, it is roundish. It seems to push a dark mass in front of it; it is as large as a satellite.

1881. Jan. 7, very bright and well-defined—it keeps the mass of matter pushed up in front of it as before; Aug. 3, a small white spot; Oct. 29, a very bright spot, with luminous and clouded train; Nov. 1, bright, and plowing its way along the equatorial regions; Nov. 12, white and distinct, about the size of a satellite, a clouded train following.

1882. Feb. 4, white—fainter, luminous train.

1886. May 13, white, luminous train.

The above times do not necessarily refer to its transit. These apparitions were doubtless the same object, as they refer to a bright body imbedded in the inner edge of the south band, and just south of the equator. From the comparisons of its size to the satellites, it was probably about two or three thousand miles in diameter. It is shown on the drawings for (Pl. I) Aug. 13, 16, Sept. 10; (Pl. II)

Sept. 24, 28, 30, Nov. 7; (Pl. III) Nov. 18, 22, 23, and (Pl. IV) Nov. 5, 1881.

The Equatorial Belts.

The equatorial belts were subject to many internal changes. These changes, though frequent, are not so great as one would be led to think from examining, say, that region just north of the Great Spot. Part of the changes are due to the continual drift of the belt past the Red Spot; thus every few days presenting an entirely different part of the belt to view from any one standpoint. As an illustration of this, we have only to follow the White Spot in its journey around the planet. I would also refer to (Pl. II) the drawings of September 30 and October 7, where a decided drift of the dusky masses is shown. These belts changed in strength and depth of color. When I first examined the belts, in 1879, the northern one was reddish, while the southern was bluish; the two being separated by a whitish, serpentine division. Though my notes contain frequent reference to the colors of these belts, it will probably be best, considering the limited space, to very briefly state a few of the observations in a general form.

Colors of the Equatorial Belts.

North of the narrow, light rift in the northern part of the north belt, the color was frequently of a deep, rich vermilion, while the rest of the belt towards the equator was of a much lighter red, though at times it became a very deep, darkish red. The south belt remained bluish for a long time, and I first began to call it reddish about the middle of August, 1880. Even in September I have called it a drab color. On September 9, 1880, when the Red Spot was in transit, the north band was a warm purple, while the south one was a cold purple. On October 10, 1880, at 10^h, part of the north band, north of rift, was a dark, heavy red, while the south band was a bluish-gray, mixed with red; while on October 13, at 8^h–9^h, they were both a deep red. On October 10, 1881, both sides of the belt were reddish, while the inside was bluish.

Forms in the Equatorial Bands, etc.

The belts were usually clearly and sharply defined at their polar edges and perfectly straight. The peculiar disturbances to which they were subject were confined to their inner edges or to parts near the equator. Besides the famous White Spot that has been mentioned, there were sometimes the most exquisitely beautiful forms at the equa-

tor. These came and went—at times filling the interior of the great belt with dusky, cloud-like forms and softly delicate plumes that were very transitory. At times the belts appeared as one, being completely filled in with one solid tint. Such was the case, 1880, September 25, when the part visible (with the Great Spot central) was dusky and evenly filled in, and the belt in every respect was one solid, unbroken shade. I have never seen it, before or since, so absolutely uniform in tint. A few days after this (September 28) faint forms began to appear in the equatorial regions near the Red Spot. The south band was usually well-defined at both edges, and rather narrow, the inner edge being more or less undulating. At other times, there were large, soft, dusky, feathery projections from it, spreading out to the equator; in almost every case, these streamed backward, towards the east limb, as if the south belt were moving faster than the equatorial region. The north band was markedly different from this. It was always much diffused towards the equator. The edges were sometimes festooned with dusky, cloud-like forms. I would refer to the drawings of Pl. III (November 10, 22); Pl. II (October 7, 10, etc.), as showing the differences in the two belts. A long light rift was frequently visible near the extreme north edge of the north band. From the fact that this always bore the same relative position to the bright spot in the south band, I infer that the north component of the equatorial band rotated in the same time as the south component; but from the retarded appearance of the dusky masses projected from the inner edge of the south band, and frequently from the north band, one might also infer a somewhat slower rotation at the equator. This, however, is a mere conjecture, with no other warrant than appearances.

In reference to this retardation of the masses projected from the south band toward the equator, I quote an observation of mine on April 1, 1886, respecting one of the most remarkable appearances that I have seen on *Jupiter:* "At 12^h45^m, three of the dark projections ranged along the inner edge of the belt and just south of the equator. I noticed that from the summit of each there extended for a short distance in a following direction, a dusky streak, looking like smoke. I was strongly impressed with the resemblance to what might be called a silhouette view of three volcanic peaks, ranged in a line and vomiting smoke, which a strong wind was carrying eastward!" (*Sid. Mess.*, May, 1886, p. 156.)

THE HISTORY OF THE FORMATION OF A NEW BELT.

In all the drawings previous to the 1st of November, 1880, a very thin line or belt is shown, just north of the north equatorial belt. In the first observation, in 1879, this narrow line was reddish, and formed a neat border to the north side of a delicate band or space that lay between it and the equatorial band. It was also the south edge or border to a delicate broad white band that encircled the northern hemisphere. Finally, the delicate band south of it faded, and became of the same tint as the light band to the north, thus leaving the border occupying the position of a distinct linear belt around the planet. This is what I have called the first north linear belt, or, simply, the first linear belt. It continued thus perfectly linear, without a mark on it, until the latter part of October, when it rapidly underwent a change so remarkable that I have thought it worth describing in detail. On the night of October 21, 1880, at 9^h30^m, this belt appeared a little swollen, or thicker than usual. On the 23d, the entire planet seemed to be undergoing a great change, so much so that I wrote in my note book: "*Jupiter* is undergoing some remarkable changes now; there are a great many degrees of shade, somewhat like ill-defined spots and light spaces, appearing in the southern hemisphere near the Great Spot. The space between the north edge of the north equatorial band and the first linear belt is deepening in tint, as it was last year—a grayish green. At 8^h the first linear belt near the following limb is knobbed in appearance, as if several little dark beads were strung on it, and at 9^h it was seen to have two pretty distinct, dusky spots on it, close to each other."

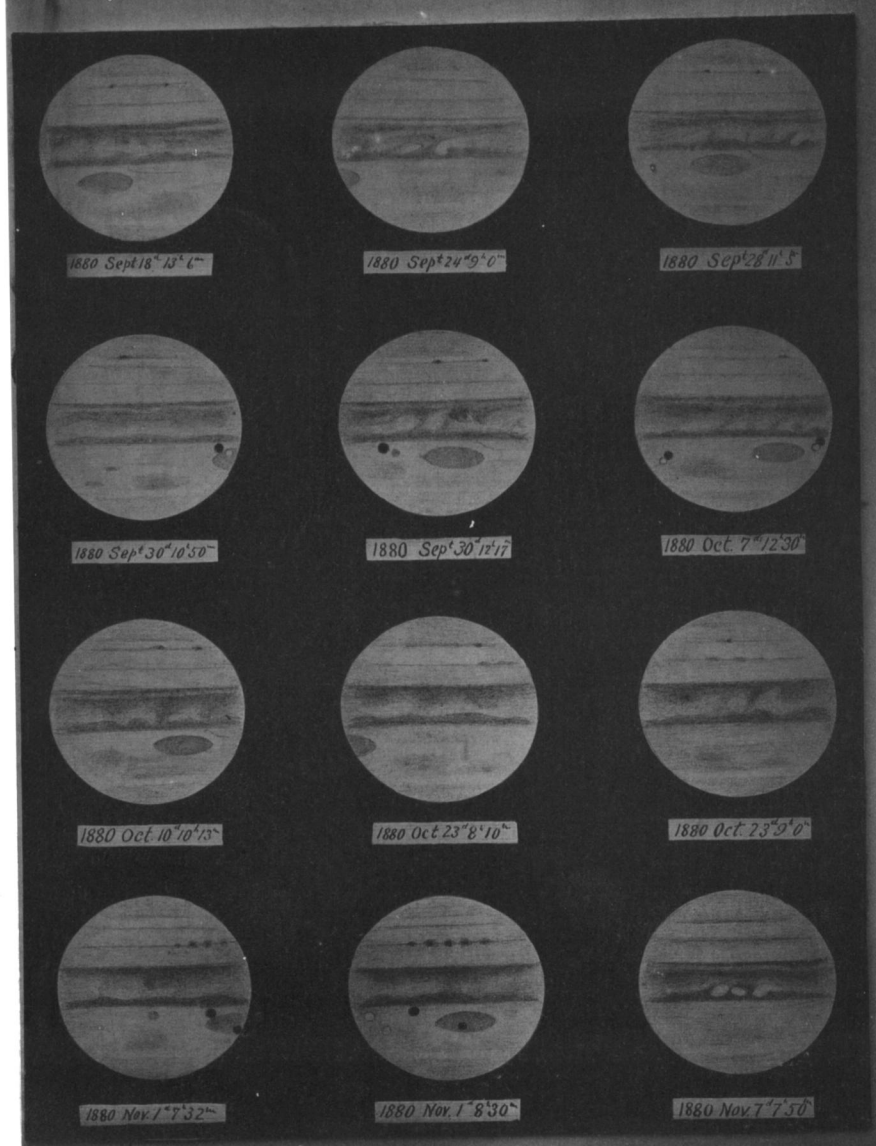
On account of the remarkable character of these changes I feel that it is proper, strictly as a matter of record, to give my notes in full:

1880. Nov. 1. *Jupiter* has been undergoing some remarkable changes. From the time the Red Spot began to appear until after its transit, the first linear belt was composed of a string of large dusky spots. I counted five, each as large as the shadow of a satellite. Under the best definition, they appeared as black as the shadows of the two satellites (I and II, shown in the drawing), and the belt elsewhere appeared thicker than usual.

Nov. 2. At 6^h30^m the affected belt observed last night appeared very heavily marked.

Nov. 3. 7^h45^m. The disturbed portion of the belt just appearing. At 8^h25^m, the affected part reaches from the following limb to near

Plate II



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midway the disc. It is heavy, broad and uneven. $8^h\,40^m$. The first portion of this is in transit; a number of roundish, cloudy masses on it clear to the following limb.

Nov. 4. It is heavily marked, and its following portion transited at $6^h\,9^m$.

Nov. 7. 8^h. The belt faint and undecided; no trace of the affected part.

Nov. 8. Near 7^h. The belt now is heavily marked all the way across the disc, and dark, with remarkably large, distinct, knotty lumps, in places quite broad with them. The disturbed region plainly visible; almost the most conspicuous part of the planet. Near 9^h, that portion of the belt visible is not affected at all, but was faint and ill-defined.

Nov. 10. From $7^h\,30^m$ until 11^h, the belt was very heavy and dark. It consisted of a strip of "veiling," pretty even at its northern edge, but undulating southwards; it was heavily nucleated at several points by heavy, blackish spots, and at these points the "veiling" was pressed outwards towards the equator. Later, that portion opposite the Red Spot, which was so heavily affected on November 1, was seen to be slightly wavy, but faint and ill-defined.

Nov. 11. Before the Red Spot had appeared the belt was affected as before. That portion opposite the Red Spot at transit was diffused and slightly wavy. Near 10^h, after the spot had disappeared, the belt was a pale blue, broader than usual.

Nov. 18. 7^h to 8^h. Opposite the Red Spot, the belt was very diffused and broad, and appeared slightly wavy where the spots of November 1 appeared.

Nov. 20. $9^h\,49^m$. The belt is very diffused and faint, with no spots on it.

Nov. 23. $8^h\,35^m$. Three large and intensely *black spots* nearing transit. The spots are as black as the shadows of the satellites.

Dec. 1. 7^h. The belt is broad, heavy and distinct across the entire disc. It is dotted with black spots. $7^h\,20^m$. It is now heavier to the preceding side of the disc, and is faded and diffused following. $8^h\,45^m$. The belt is now faint and diffused across the entire disc.

Dec. 2. $6^h\,51^m$. It is faint and diffused, and no dark spots on it. At $7^h\,37^m$, it is heavy with separate "blocks" or oblong spots. These are probably the ones seen on November 1, which have gone completely around the planet, and have now arrived at the point where they where first seen. They are about as conspicuous as

the equatorial belts, and are moving around the planet with great velocity.

Dec. 5. The large spots have drifted past the Red Spot, and appear as at last observation—broken—forming a disjointed belt. At 8^h, the belt is composed of a number of dusky spots that stretch from limb to limb.

Dec. 7. $7^h\,19^m$. The belt is heavy and broken.

Dec. 9. 8^h to 10^h. The belt is heavy and uneven. The south edge has a light rim or border.

Dec. 10. The northern hemisphere is delicately beautiful. The south side of the new belt consists of beautiful curves, their inner (south) edge bordered with a light line. I notice that the equatorial edge of the north equatorial band has the same or corresponding curves to those in the new belt.

Dec. 14. $6^h\,35^m$. The new belt consists of several large dusky spots.

Dec. 29. $7^h\,40^m$. The new belt faint, the scolloped edge seen with difficulty.

Dec. 30. About 9^h, it is heavy and undulating.

Dec. 31. 8^h. The new belt is faint.

1881. Jan. 7. 8^h to 9^h. The new belt is deeply scolloped—long and regular sweeps; it fades northwards. There is no white rim to the scollops. The belt diffuses north as a grayish shade all over the northern hemisphere. The second and third linear belts that crossed the northern hemisphere in 1880 cannot be seen.

March 6. $7^h\,30^m$. The new belt is much scolloped.

July 2. 15^h. There is a heavy diffused belt north of the equatorial belts, where, in 1880, existed the first linear belt. This is the final result of the spots that broke out on it November 1, 1880.

July 9. $14^h\,30^m$. The new belt is broad and diffused, and of a brick-dust red.

Oct. 3. The new belt is very diffused. There is a dark line running through it a little north of the middle of the belt. [Is this the first linear belt?] A small, white spot, like a satellite, on its south edge, transited at $10^h\,15^m$.

Oct. 14. 10^h. The new, diffused, reddish belt is double.

This is the complete history of the formation of at least *one* of the belts of *Jupiter;* and probably no more remarkable outburst has been witnessed.

During the time these striking changes were taking place the

weather was very bad, and only occasional glimpses of the planet could be had. These glimpses, though, gave sufficient evidence of the rapid changes that were taking place. These changes were so rapid and peculiar, and the weather so unpropitious, that no transits that could be positively identified as belonging to the same portion of the affected belt could be obtained, and therefore the motions of these spots could only be estimated. But it was clearly evident that they were extremely rapid. If the sketches refer to identical objects, the period, with reference to the Red Spot, would not be far from thirty days, or two-thirds of the period of the White Spot, with reference to the Great Spot.

Let us briefly review what the notes tell us about this disturbance. For, at least, over one year, a thin, uniformly even stripe around *Jupiter* existed north of his equatorial belt. About the last of October, 1880, both hemispheres of the planet were greatly affected by a disturbance that finally culminated in a great outbreak on this thin stripe, just mentioned. First, it became swollen in places; then, lumpy spaces appeared on it; next, small black spots were formed, each with a penumbra—not unlike a sun-spot; these had a very rapid motion westward on the planet, and enlarged and increased in longitudinal extent, becoming large, oblong, dusky spots, without a black nucleus. They then diffused into a "veiling," with condensations in it. This "veiling" became beautifully scolloped, its southern side consisting of graceful, light-rimmed curves, which decreased in sweep as they extended eastwards. Finally, these encircled the planet completely, diffusing northwards quite to the pole. The energies that produced the disturbance finally died out, and the beautiful curve-bordered belt lost its characteristic features and toned down to a broad, diffused, red belt, surrounding the planet; and this finally became double, and was apparently a fixed feature of the surface when I ceased to observe it.

The Polar Caps.

The north polar cap was variable in its color and in the distance to which it extended. It was frequently noted to be of a delicate wine tint; at other times it was pale gray. Its usual limit was the third linear belt, though on several occasions it extended nearer the equator. At these times the third belt was seen crossing it.

The edges of the south cap were seldom well-defined. I have never seen it of a warm tint. These caps have never been very deeply marked. One striking fact was noted on several occasions.

When dawn had whitened the sky the poles appeared to grow darker and more dusky in color. There was usually a marked difference in the appearance of the northern and southern hemispheres of the planet. The northern was free of spots, except several tiny *black* ones, which were visible for a long time on the third linear belt, and which did not have a greatly different period from that of the Red Spot. Graceful, narrow linear belts crossed this hemisphere, and light bands were often seen. In the southern hemisphere there was no such symmetry. The Great Red Spot, dusky shadings, strips or fragments of belts, were the characteristic features of the southern hemisphere.

It is a very difficult question as to which portion of the surface of the planet is the highest—whether the belts are at a lower depth than the whiter surface or otherwise. During these observations I was frequently impressed with the idea that the general matter of the equatorial belts was at a lower altitude. I was particularly struck with this on several occasions. A peculiar brushing-out or smearing of the bright surface adjacent to the south band, which was recorded on several dates, had every appearance of a blending of the light surface over and above the belt. Several times in 1886 a luminous spot was seen close to the northern edge of the north equatorial band that seemed to push the white surface over and above the belt. The more rapid rotation of the belt is also consistent with its being at a lower altitude.

At a number of occultations of the satellites I watched carefully for any evidences of their being seen through the edges of the planet, but saw nothing of the kind. Professor HOLDEN informs me, however, that, with the thirty-six-inch equatorial, the whole disc of a satellite has been visible within the planet's atmosphere, at every occultation he has observed. (See, also, the observations of 47 *Libræ* by *Jupiter*, as observed by Professor HOLDEN and myself, June 9, 1888. *A. J.*, vol. 8, p. 64.)

I would call special attention to the second drawing of 1880, November 1 (Plate II). There is a large lithograph of *Jupiter* published by the SCRIBNERS, from a drawing by TROUVELOT. This was made in Cambridge, Mass., November 1, 1880, ($9^h\ 30^m$, Cambridge mean time). The difference of longitude between Nashville and Cambridge is $1^h\ 3^m$. My drawing was made at $8^h\ 30^m$, Nashville mean time, adding the difference of longitude, and we have $9^h\ 33^m$, Cambridge mean time, for my drawing, or within three minutes of the time of the drawing by TROUVELOT. That is to say, that while my

pencil, in Nashville, was marking on the paper, TROUVELOT, at Cambridge, Mass., was, at that identical instant, drawing the same thing. The two drawings are exactly similar in the main features. His telescope was larger than mine, and he, therefore, saw more details. To the left below the belt, on this drawing, are the first and second satellites; the first nearer the belt. On the Red Spot is the shadow of the second satellite, while near the equatorial belt is the shadow of the first moon.

I have collected nearly all the observations of transits of spots over the central meridian of *Jupiter's* disc, and present them in the following table. I would state, in reference to these observations, that the first ones to the latter part of September may be affected by an error in the times of as much as two or three minutes outside of the error of observation. I had no means of determining my time, and depended upon the tower clock of the University, which, I afterwards found, had not been carefully looked after during the vacation season. I therefore give them with the above caution. I regret this; for I believe the observations themselves were made with much accuracy for simple eye-estimates. Some that were obviously far out, from the above cause, I have rejected altogether.

In conclusion, I would express my indebtedness to Professor HOLDEN, without whose interest and encouragement these observations and drawings would never have been published.

DESCRIPTIONS OF THE DRAWINGS.

Plate I.

1879. Oct. 3. Shows the Red Spot and the area of light surrounding it, and the peculiar diffusion of the south band towards the south, which forms a bay around the following end of the spot. North of the equatorial bands is shown the narrow linear belt, which later on plays an important part in the drawings. This we have designated the first linear belt north.

1880. July 24. A very small dusky spot is seen between the equatorial belts and the south pole. The Red Spot is appearing at the following limb.

July 30. The peculiar mass of shading, referred to in the notes, is seen attached to the south preceding portion of the Red Spot.

Aug. 13. This shows the famous White Spot in the south part of the equatorial bands, near the following limb.

Aug. 16. The White Spot is nearer the Red Spot.

Aug. 17. Shows a group of small spots, and the mass of shad-

ing, and the Red Spot just coming into view around the following limb. The left-hand one of the three small spots is the same as that shown in the drawings of July 24 and August 1.

Sept. 10. The White Spot is shown in one of its brightest phases, with a luminous train following it near the equator. It has passed the Red Spot and left it far behind.

Sept. 16. Shows the shading now separated from the Red Spot, which it is leaving slowly behind.

Plate II.

1880. Sept. 18. This shows the thin red line springing from the south side of the equatorial belt and streaming backwards parallel to the equator, near the following end of the Red Spot. Two very small, very black spots are seen. One of these was visible for a great length of time on the second linear belt north. Though the Red Spot is shown in this drawing, the white one is invisible, being indeed on the other side of the planet at this time.

Sept. 24. The Red Spot is disappearing at the preceding limb, while the White Spot, with its train of light, is near the middle of the disc.

Sept. 28. The Red Spot is just past the middle of the disc, and the White Spot is fully within the following limb.

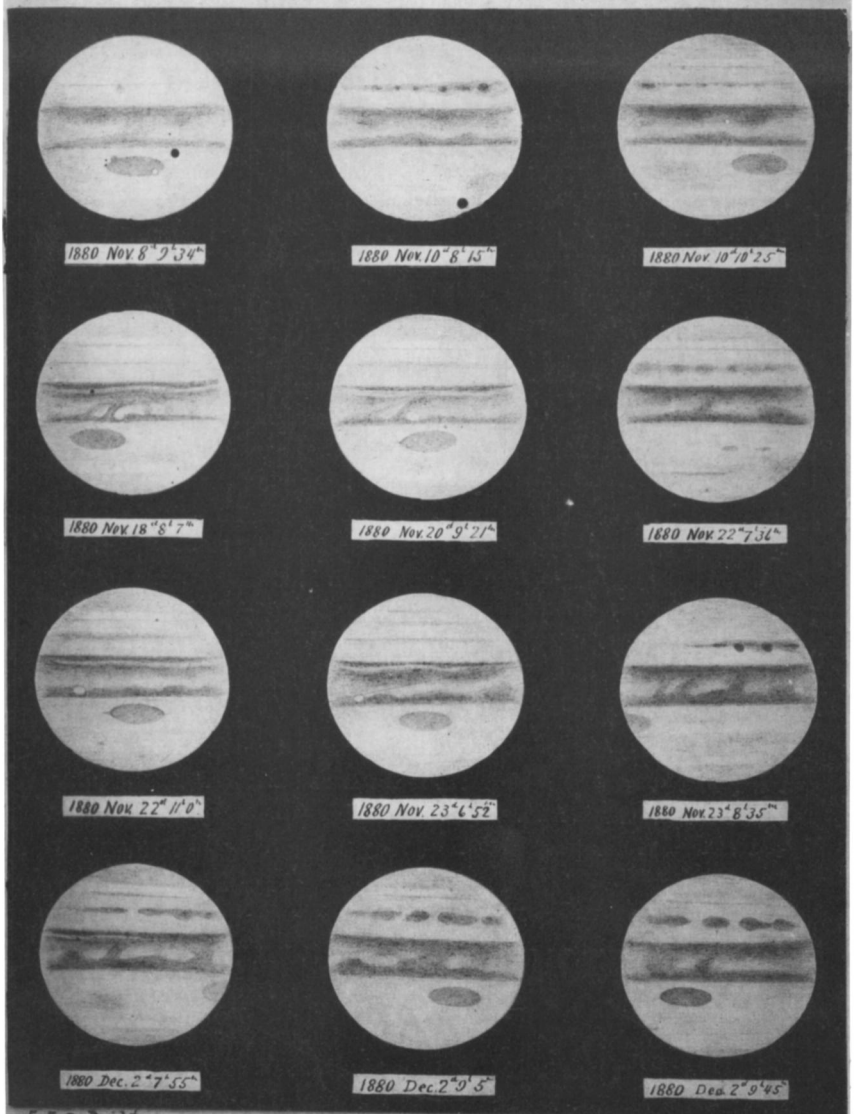
Sept. 30. (I) Satellite I is seen on the Red Spot, while its shadow is on the edge of the spot. The shading and two of the small spots in the southern hemisphere are also seen. (II) Satellite I and its shadow have now left the Red Spot. On this occasion I transited most of the disc as a dusky brown spot, south following its shadow. The White Spot is appearing at the following limb.

Oct. 7. Satellites I and II are in transit, partially hiding their shadows, which are close north following them.

Oct. 23. (I) The Red Spot is disappearing, and some dusky lumps are coming into view on the first linear belt north. These are the first indication of the great outbreak on that belt. (II) These swollen places in the belt are shown in transit.

Nov. 1. (I) The Red Spot is appearing, while the shadow of I is just skirting its north preceding end, and the shadow of II is on the spot. Near the middle of the disc, south of the equator, satellite I itself is shown as a dusky spot near transit, while satellite II is lost in the brightness of the disc. Near the north following limb a string of dark spots is coming into view on the first linear belt. (II) Both satellites now appear as small pale discs, relieved by the slight

Plate III



Jupiter.

duskiness of the planet near the preceding limb. The shadows have changed their places with respect to the Red Spot. The row of dark spots on the first linear belt is now in transit. These look like sun-spots—a black umbra surrounded by a penumbra. These are, doubtless, the same spots that are shown in an incipient stage of development in the sketches of October 23. They are, therefore, in rapid motion around the planet. (Compare their relative position to the Red Spot in the first drawing of October 23 with that of the second drawing of November 1.)

Nov. 7. We have the White Spot in this drawing on the opposite side of the planet to the Red Spot. Two other bright spots are just ahead of it.

Plate III.

1880. Nov. 8. The second satellite is seen as a white spot on the south following end of the Red Spot, while I is partially on the north preceding end as a dusky spot, and its shadow is shown to the right of the center below the equatorial belt. That portion of the first linear belt north now visible with the Red Spot has not as yet been affected by the eruptive spots.

Nov. 10. (I) The shadow of III is seen at a high southern latitude, and a mass of dusky shading is north following it. Another phase of the new spots on the first linear belt is shown. (II) The Red Spot is now visible, and the affected part of the belt has been carried off the disc by rotation. That portion now seen is faint and wavy.

Nov. 18. The White Spot is in one of its brilliant phases, just above the following end of the Red Spot.

Nov. 20. The White Spot has now moved to a point near the preceding end of the Red Spot, and is in one of its quieter phases.

Nov. 22. (I) Another phase of the northern spots is shown. The two small spots in the southern hemisphere have been shown in previous sketches. The Red Spot is not in sight. (II) The Red Spot and the White Spot are both visible—the White Spot having left the Red Spot far behind.

Nov. 23. (I) The distance between the White and Red Spots has sensibly increased since the drawing of last night. (II) The Red Spot is disappearing, and the first portion of the affected belt is coming into view at the north following limb.

Dec. 2. (I), (II), (III) show further phases of the disturbance.

Plate IV.

1880. Dec. 9. Shows the spots becoming connected by long loops bordered with a brilliant line on the equatorial side.

Dec. 10. (I) Another portion of the new belt visible when the Great Spot is leaving the disc—the shadow of a satellite on it. (II) This drawing was made after the Red Spot had disappeared.

1881. Aug. 29. In the place of the first linear belt north there is now a broad diffused reddish belt that completely encircles the planet. The remarkable spots and the beautiful light-rimmed curves have disappeared, and all the other singular transformations that the first linear belt north underwent have finally ended in the formation of this now persistent diffused red belt.

Nov. 5. The Red and the White Spots are again near each other. The diffused red belt, the scene of the great disturbance of 1880, remains unchanged. Two of the small black spots previously seen are shown on the second linear belt north—which, suffering almost total obliteration during the changes of 1880, is now as marked as ever.

1885. May 12. The Great Spot is now very faint. The south equatorial band diffuses southwards around the following end of the Red Spot, as in 1879.

1886. April 22. A white cloud has formed over the middle of the great Red Spot, almost obliterating it. The peculiar bay formed around the following end of the spot by the south band is now very persistent.

I have observed a few abnormal transits of Satellites I, III and IV, which are given here, so that they may be available for a study of the causes of these dark and black transits.

SATELLITE I.

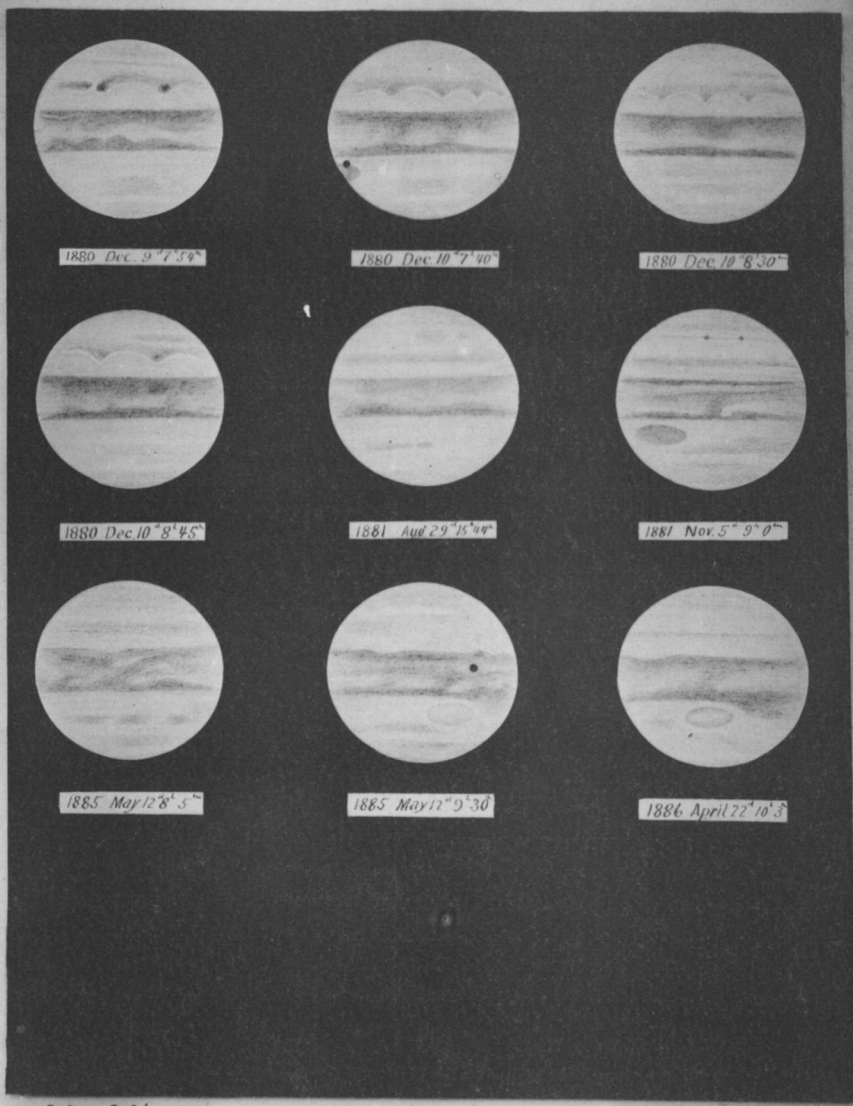
1880. Sept. 30, occasionally seen during transit as a brownish spot; Nov. 1, seen in mid-transit as a dusky spot; Nov. 8, seen in mid-transit as a dusky, brownish spot; Dec. 1, seen in mid-transit quite plainly as a dark spot—quite dark.

SATELLITE III.

1879. Aug. 2, very black nearly all the way across—mistaken for shadow; Sept. 14, black during transit.

1880. Sept. 28, carefully watched throughout transit, not visible except near limbs—not a black transit; Dec. 30, at $8^h\ 30^m$, seen in a high south latitude as a small, black spot; continued visible as

Plate IV



E.E.B. Del.
E.E.B. delt.

Jupiter.

black spot until near *p.* limb, and only lost its blackness at $9^h\ 4^m$. Ten minutes after emergence it was certainly as bright as that part of disc on which it appeared as black as a shadow.

1880. Nov. 10, the shadow of III appeared fuzzy and not black. It seemed to be affected by penumbra.

1881. Oct. 13, at inferior conjunction it passed the south pole with only three-quarters of its disc on the planet—carefully estimated.

1883. Feb. 12 ($9^h\ 40^m$), small, black.

1885. May 9 ($7^h\ 15^m$), on north edge of belt very black, and remained dark until close to limb.

SATELLITE IV.

1885. Feb. 27, at $6^h\ 15^m$, it is as black as its shadow, and about half as large—it remained dark up to nearly the moment of emergence.

1886. May 8 ($9^h\ 20^m$), IV near north pole, very black.

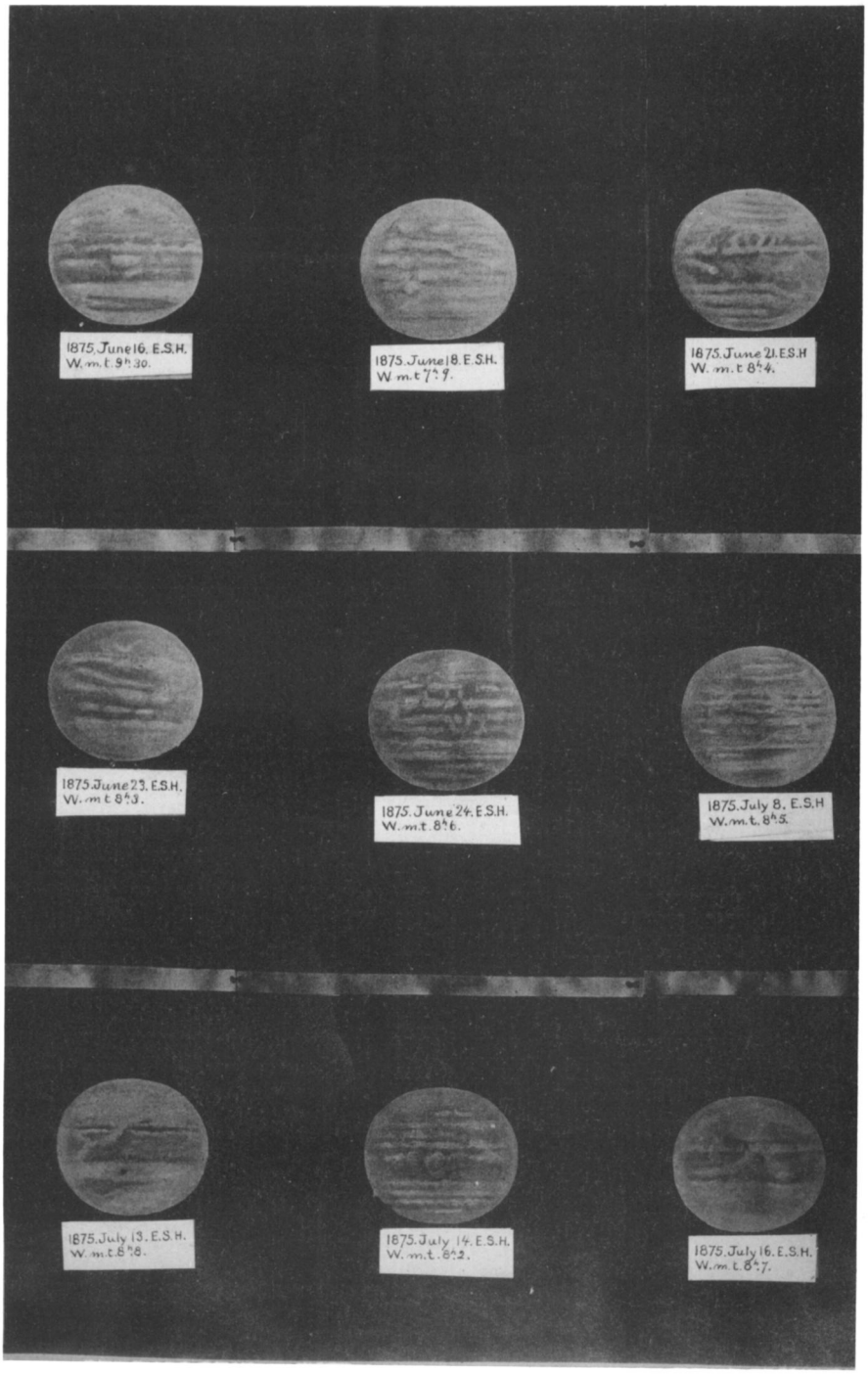
OBSERVED TRANSITS OF SPOTS ON *JUPITER*.

(NASHVILLE MEAN TIME.)

DATE.	RED SPOT.			WHITE SPOT.	*a*	*b*	*c*	*d*
	P. End.	*Middle.*	*F. End.*					
1880.	*h. m.*	*h. m.*	*h. m.*	*h. m.*	*h. m.*	*h. m.*	*h. m.*	*h. m.*
July 10.	14 40	15 22	15 47	....	....	....	....	....
" 17.	15 20	15 44	16 04	....	....	....	....	....
" 24.	16 12	16 40	16 57	....	....	....	....	....
" 29.	15 17	15 43	16 11	....	14 00	....	....	....
Aug. 1.	16 52	17 18	17 42	....	15 18	....	....	....
" 7.	....	....	....	....	16 09	....	....	....
" 11.	....	11 32	12 01	....	....	....	....	....
" 13.	12 36	13 04.5	13 32	....	....	....	....	....
" 16.	10 16.5	10 35	10 56	....	....	10 36	....	....
" 17.	15 55	16 19	16 41	....	14 14	....	....	....
" 23.	10 54.5	11 19	11 40.5	....	....	....	....	....
" 28.	....	10 24.5	10 48.5	....	....	....	....	....
" 30.	11 34.7	11 58.2	12 24.2	....	....	....	....	....
Sept. 9.	9 51.7	10 15.2	10 39.2	....	....	....	....	....
" 14.	....	9 27±	....	....	....	10 21	....	....
" 15.	....	....	....	....	....	9 47	....	....
" 16.	10 32	11 02	11 24	....	....	....	....	....
" 18.	12 14	12 37.7	13 03	....	....	12 22	....	....
" 25.	12 58	13 24	13 45	....	10 46	....	....	....
" 28.	10 28	10 53	11 17	....	....	10 38	11 40	....
" 30.	12 01.5	12 29.5	12 54	....	9 48	12 11	....	....
Oct. 1.	7 57	8 25	8 52	....	....	....	....	7 28
" 6.	7 01.5	7 29.5	7 57.5	....	....	....	8 18	....
" 7.	12 45	13 13	13 40	....	10 24	....	....	....
" 10.	10 13.5	10 39.5	11 08.5	....	....	10 26.5	....	....
" 13.	7 44	8 10	8 36	....	....	....	....	....
" 20.	8 29	8 53	9 17	....	....	....	....	....
" 22.	....	10 30	....	....	....	....	....	....

DATE.	RED SPOT.			WHITE SPOT.	*a*	*b*	*c*	*d*
	P. End.	*Middle.*	*F. End.*					
1880.	*h. m.*	*h. m.*	*h. m.*	*h. m.*	*h. m.*	*h. m.*	*h. m.*	*h. m.*
Nov. 1.	8 19	8 48	9 10.5	....	....	....	....	....
" 4.	....	6 15	6 39	....	....	....	....	....
" 7.	....	....	....	7 59	....	....	....	....
" 8.	9 06	9 31	9 57	....	....	....	....	....
" 10.	10 44	11 09	11 33	....	....	....	....	....
" 11.	6 34	6 57	7 25	....	....	....	....	....
" 18.	7 17	7 42	8 09	....	....	....	....	....
" 20.	8 58	9 22	9 48	....	....	....	....	....
" 22.	10 40	11 01	11 29	10 18	7 46	....	....	9 07
" 23.	6 32	6 53	7 20	....	....	....	....	....
Dec. 2.	8 56	9 15	9 41	6 27	....	....	7 33	7 23
" 5.	6 28	6 46	7 11	....	....	....	....	....
" 6.	....	....	....	8 53±	....	....	....	....
" 7.	7 59	8 23	....	....	....	....	....	....
" 9.	9 37	10 01	10 24	....	....	....	....	....
" 14.	8 46	9 09	9 34	9 20	....	....	....	7 05
" 29.	....	....	....	7 41	....	....	....	....
" 31.	7 45	8 08.5	8 33	....	....	....	....	....
1881.								
Jan. 7.	8 39	9 01	9 24	8 02.5	....	....	....	....
Mar. 6.	6 52	7 14	7 36	....	....	....	....	....
July 2.	....	....	15 21	....	....	....	....	....
" 9.	15 12	15 34	15 57	....	....	....	....	....
" 11.	16 47	....	....	....	....	....	....	....
" 21.	15 04.5	15 27	15 50	....	....	....	....	....
" 28.	15 53	16 12	16 36	....	....	....	....	....
Aug. 3.	....	....	....	14 42.5	....	....	....	....
" 5.	...	....	....	15 46	16 06	....	....	....
" 29.	....	....	....	....	15 39.5	....	....	....
Oct. 10.	....	....	17 32	....	....	....	....	...
" 29.	....	....	....	10 25	....	10 15±	....	....
Nov. 3.	....	6 50±	....	8 24	....	....	....	....
" 5.	8 09	8 30	8 54	9 34	....	9 20	....	....
" 12.	9 52	9 14	9 42	8 44	....	....	....	....
" 15.	....	6 45	7 08	....	....	....	....	....
" 26.	....	....	....	7 27	....	....	....	....
" 29.	8 54	8 15	8 37	....	8 30±	....	....	....
1882.								
Jan. 23.	8 19	8 40	9 03	....	....	....	....	....
Feb. 4.	8 08	8 28	8 49	9 07	....	....	....	....
April 27.	....	....	6 50±	....	....	....	....	....
1885.								
April 25.	....	10 41.5	....	7 56.5	....	....	....	....
May 12.	....	9 43	....	....	....	....	....	....
May 13.	....	....	....	8 48	....	....	....	....
1886.								
April 22.	....	10 18.6	....	....	....	....	....	....
1888.								
*July 24.	11 51.9	12 08.4	12 29.8	....	....	....	....	....
1889.								
*May 31.	....	....	15 09.3	....	....	....	....	....
*June 9.	....	....	17 48.4	....	....	....	....	....
" 17.	....	13 53.0	....	....	....	....	....	....
*July 2.	....	11 19.1	....	....	....	....	....	....

* With twelve-inch at Lick Observatory. Like the others, in Nashville mean time.


1875. June 16. E.S.H.
W. m. t. 9h 30.
1875. June 18. E.S.H.
W. m. t 7h 9.
1875. June 21. E.S.H
W. m. t 8h 4.
1875. June 23. E.S.H.
W. m. t 8h 3.
1875. June 24. E.S.H.
W. m. t. 8h 6.
1875. July 8. E.S.H
W. m. t. 8h 5.
1875. July 13. E.S.H.
W. m. t. 8h 8.
1875. July 14. E.S.H.
W. m. t. 8h 2.
1875. July 16. E.S.H.
W. m. t. 8h 7.

The transits of a few objects were observed with the six-inch, at the Vanderbilt University Observatory, as follows:

DATE.	*e*	*f*	*g*
	h. *m.*	*h.* *m.*	*h.* *m.*
1885. April 21.....	8 02.5	.....	.....
" " 22.....	.....	7 05.5	6 55.7
" " 25.....	7 08.2	.....	.....
" " 29.....	.....	7 54.5	7 46.5
" May 9.....	8 42.5	.....	.....

NOTE (explanatory of the table of transits).— *a* is the small spot mentioned as having been seen 1880, July 24, and subsequently; *b* is a small black spot, the *p*. of two shown on the second linear belt north in the drawing of 1880, September 28, and subsequently; *c* is the second of these two black spots; *d* is the shading spoken of in connection with the Red Spot; *e* is a luminous spot, sometimes recorded as a notch in the north edge of the north equatorial band, probably not all the same object; *f* is a very small, intensely black spot *on* the south part of the equatorial belt—round, and like a satellite's shadow, but smaller; *g* is a luminous spot or notch in the north edge of north equatorial band.

DRAWINGS OF *JUPITER* MADE WITH THE 26-INCH EQUATORIAL, AT WASHINGTON, DURING 1875.

BY EDWARD S. HOLDEN.

During June and July, 1875, I made drawings of *Mars* and *Jupiter*, in colored crayons, for the purpose of comparing the tints on these two planets. The drawings were all made with the twenty-six-inch equatorial of the United States Naval Observatory, usually with a magnifying power of 400, and no pains were spared to make correct delineations, both as to forms and colors. From one cause and another, these drawings have not been published.

I beg to present a photograph of the sketches of *Jupiter* to the Society.

The original colored drawings [exhibited to the meeting] will be deposited in the library of the Lick Observatory, where they will always be available for comparison with more recent work. Below, I give the few notes which should accompany the drawings, which are reproduced in Plate V. It will be interesting to compare these